5G S-NPN (STANDALONE NON-PUBLIC NETWORK) FOR PROFESSIONAL MEDIA PRODUCTION

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ABSTRACT

Live media content production usually requires deploying large amounts of equipment and crew at the event location or studio, all connected to the production facilities. The 5G-RECORDS project explores using 5G for an interconnected wireless system that simplifies logistics while still providing all functions needed for media production. The project has developed an architecture and new components for a multi-camera production, with 5G-enabled cameras deployed on a 5G S-NPN (Standalone Non-Public Network) and using an interoperability and standards-based approach. This architecture supports discovery, connection and management of the wireless cameras, enables control across multiple locations, minimises latency and seamlessly integrates with wired infrastructure. We argue that the opportunities offered by such use of 5G S-NPN bring broadcasters multiple benefits, which extend to cloud and hybrid production scenarios.

INTRODUCTION

Media production has had wireless camera capabilities for over 50 years. During this time the industry has evolved to enhance quality and increase capacity used by these wireless links. The latest radio technologies promise high quality, low latency IP connectivity and broadcasters are exploring how this technology may be deployed in a modern studio environment.

Supporting IP-Based Live Production

Media production is currently moving towards IP-based (Internet Protocol) solutions, as broadcasters manage content across studio and OB (Outside Broadcast) networks. These transitions offer new opportunities for content producers and have been an essential part on recent advances in both cloud-based and remote production deployments.

Wireless cameras are being increasingly used alongside wired cameras. Current radio camera solutions use protocol stacks similar to those used for DVB-T (Digital Video Broadcasting - Terrestrial) services over a specialist spectrum, and interfacing with the production facilities is done via SDI (Serial Digital Interface). Since that interface is unidirectional, there is no backchannel to support ancillary services such as camera control or return video. Adding these services requires the deployment of additional radio channels, complicating the overall installation and management, as well as requiring dedicated workflows.

Key elements for wireless media production include:

- High bandwidth, low latency uplinks for programme video
- Multiple lower bandwidth downlinks for communication and control
- Time-synchronization of multiple cameras
- Interoperability with existing production capabilities

An ideal solution would therefore be an IP radio offering high bandwidth, low latency bidirectional traffic all the way to the camera head.

5G: From Mobile Telephony to Media Production

The H2020-ICT-42 project 5G-RECORDS ‘5G-RECORDS (15)’ considers that 5G technologies have the potential to support media production workflows (Figure 1).

Although 5G is a suite of network and radio technologies that have emerged from the mobile industry, it can also support applications beyond mobile telephony. It is a fully IP-based system, which offers high bandwidth and low latency wireless connectivity in uplink and downlink direction.

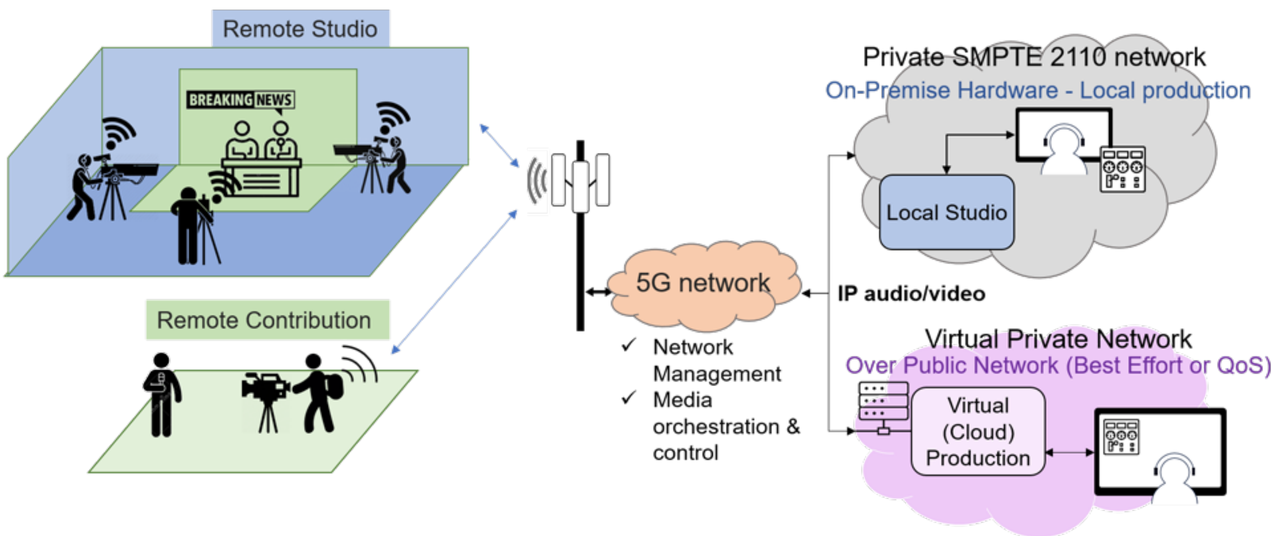

Figure 1 - A 5G wireless studio

However, replacing existing radio camera solutions in light entertainment and sporting event coverage using 5G presents certain challenges for a practical deployment. These include how to provide solid connectivity between cameras and other equipment. These systems then need to be integrated into production networks, and we may need to optimise networks away from supporting a large number of downloading devices, over to a smaller number of devices with high bandwidth uplink.

5G S-NPN in a Multi-Camera Studio Environment

One key element of 5G is the ability to support private networks and for these networks to be deployed in industrial settings to support different vertical sectors such as manufacturing, transportation, and smart cities. As standalone capacities are essential for media production, 5G-based private networks can become an asset to live media production.

5G private networks can be supported in a variety of ways, depending on the requirements. In the type of private network that we are looking into, 5G S-NPN, a dedicated 5G System is operated within a separate radio spectrum to other public 5G Systems. Radio spectrum is allocated to the media production event and the media producer may use 5G System features and configurations as needed. This enables control of 5G System usage and the capacity allocation to devices, which is of paramount importance in a media production environment.

Focusing on the use case of a professional live media production with multiple wireless cameras, we have developed an architecture that takes advantage of the opportunities offered by 5G S-NPN and overcomes the challenges of 5G for practical deployments.

This paper describes the work performed by the 5G-RECORDS project in developing components of the 5G S-NPN architecture for this multiple wireless camera production scenario, and how broadcasters can benefit from the opportunities offered by 5G S-NPN.

RELATED WORK

Particularly relevant related work is the 5G Infrastructure Public Private Partnership (5G PPP) joint initiative '5GPPP (13)', which 5G-RECORDS is a part of. 5GPPP is an "initiative between the European Commission and European ICT industry aiming at delivering solutions, architectures, technologies and standards for the next generation communication infrastructures of the coming decade" for different verticals such as automotive, media, energy, food and agriculture, healthcare, manufacturing, public transportation and many more.

Several industry bodies – including 3GPP '3GPP (9)', EBU 5GCP 'EBU (2)', and 5G MAG '5G-MAG (14)' – have worked on the definition of requirements and standards for professional live media production in both public and non-public networks.

There has been significant work to date on understanding how 5G may be deployed for media production. The most obvious is the use of bonded cellular to support contribution over public 3G/4G/5G networks. These solutions have evolved over the last decade to become a stable part of news and programme contribution. They are simple to operate and work over consumer grade public mobile networks.

While these solutions are ideal for contribution workflows, often replacing the need for a satellite uplink function, reducing costs on location, and enabling more live contribution, they are not suitable for use alongside wired cameras in a live studio or OB due to quality, latency, and reliability characteristics.

5G-RECORDS adds the live production scenario, thereby leveraging the potential of 5G S-NPN to create an integrated production system, in which wired and wireless systems cooperate seamlessly, thanks to innovative components which are not yet available in the market.

A LIVE MEDIA PRODUCTION ARCHITECTURE WITH MULTI-CAMERA WIRELESS STUDIO

Existing media production solutions that use dedicated radio spectrum to transmit video are very mature but require bolt-on links for ancillary services (such as control, audio or reverse video). Meanwhile, there are several wired IP-based technologies using compressed and uncompressed media to support the production workflow. The SMPTE ST 2110 suite ‘SMPTE (8)’ standardises how to carry uncompressed video and audio over RTP (Real-time Transport Protocol). However, these solutions target fixed installations. Wireless solutions will need to use compressed video and it is therefore necessary to include encoding and decoding into the architecture.

Therefore, we wanted to build a simple architecture that would provide interoperability and seamless integration between these existing solutions and protocols.

Use Case Scenario

We set out to explore a scenario in which a production crew could easily establish a production set-up with multiple wireless cameras in just a few steps:

- The engineering manager sets up, rigs and configures a 5G radio and core network, and connects to the media production.
- The camera crew mounts a wireless enabled camera.
- When the wireless camera is put into position with other wired cameras and switched on, the 5G S-NPN network discovers the unit (as it is self-provisioning), and the camera is configured.

The production setup is now ready and with a full IP connection between cameras and their ST 2110 production site. Before and during production, services can be assigned, and the camera interface unit remotely controlled. Cameras are synchronised with a centralised PTP (Precision Time Protocol), thereby it is possible to cut seamlessly between 5G cameras and wired cameras. Assuming spectrum and bandwidth are available, scaling production by adding more 5G cameras is easy enough: 5G S-NPN are by nature highly scalable, as it is based on commodity hardware and its core functionality is software based.

Architecture Overview

The architecture that 5G-RECORDS has developed supports this scenario by focusing on how to set up the cameras, mix wireless and wired sources, improve quality (QoS, latency, synchronization), and control devices remotely. It introduces several novel components, not available in the market, that integrate the 5G wireless system into a media production, namely:

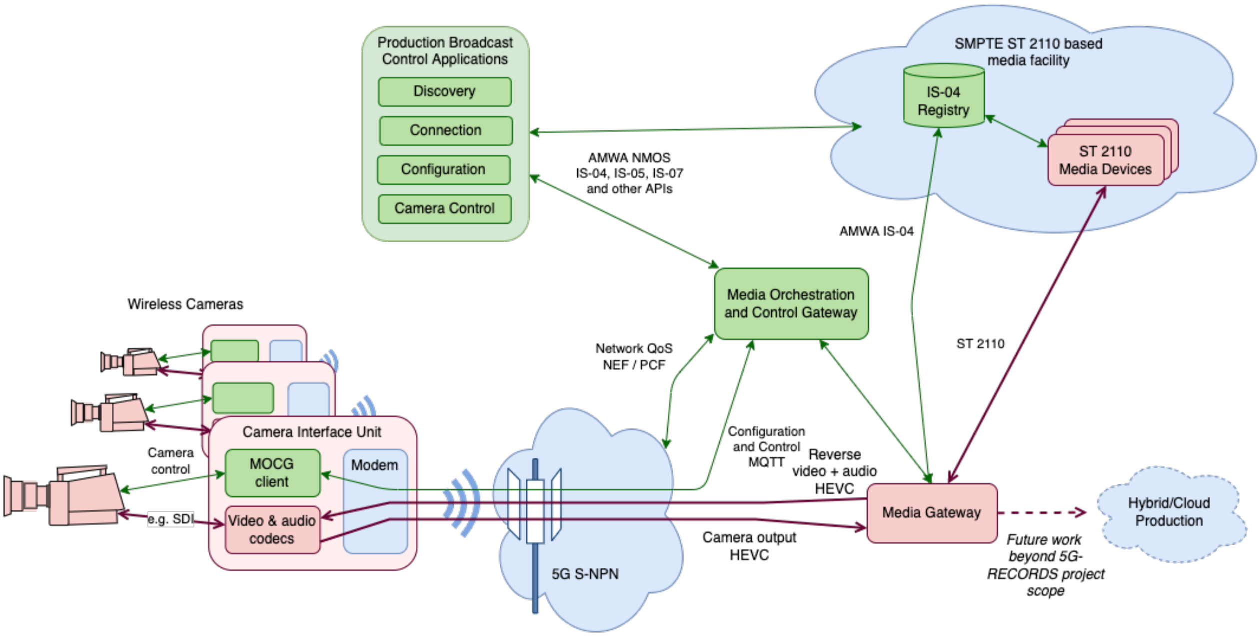

Figure 2 - Architecture overview

- A Camera Interface Unit (CIU) that provides low latency encoding, 5G modem, and other functionalities.
- A Media Orchestration and Control Gateway (MOCG): a component that demonstrates how control plane interoperability between different media networks can be achieved using NMOS (Networked Media Open Specifications) interfaces 'AMWA (1)'.
- A Media Gateway (MG) that handles decoding for uplink video and encoding for return video. We are exploring HEVC (High Efficiency Video Coding) compression for this, with an appropriate low latency profile.

The CIU encapsulates the encoded video data directly into RTP IP stream, separately from audio or other data. 5G-RECORDS selected a design that avoids multiplexing of audio, video and other data into a MPEG2-TS (Transport Stream) container format.

All cameras are time synchronised to the same time domain as the Media Gateway. The MG can process the media data independently according to the media timestamps.

The various components of the architecture are connected as illustrated in Figure 2, and are running over a 5G S-NPN configuration which supports media production.

In terms of the 5G network itself, for this project the most important network functions from the complete realization defined in the document TS 23.501 '3GPP (10)', TR 26.805 '3GPP (11)', and TR 38.300 '3GPP (12)', are:

- The User Plane Function (UPF), responsible for packet routing and forwarding among other things.
- The gNB: a node that handles the 5G radio protocols towards 5G devices and is connected to the 5G core network.

- The Network Exposure Functions (NEF) / Policy Control Function (PCF) that facilitates access to exposed network services and capabilities.

The 3G standardization partnership 3GPP (3rd Generation Partnership Project) defines also a User Equipment (UE), which is realised in 5G-RECORDS as a combination of the CIU and the camera of Figure 2.

Depending on the deployment, the MOCG may interact with the NEF directly with a Policy Control Function (PCF) or through other Network Management (MN) solutions.

Camera Interface Unit (CIU)

The CIU (see Figure 2) has the following capabilities:

- Encode using HEVC (High Efficiency Video Coding) and decode multiple video format resolutions (e.g., high definition, ultra-high definition) at different bit rates (in the range of 20Mbps to 50Mbps for high-definition resolution), and with low latency settings.
- Encode and decode audio.
- Generate a genlock signal for the camera from the timing source signal coming over the 5G network.
- Produce native RTP streams.
- Timestamp the RTP streams using the same timing source signal.
- Communicate with the MOCG.
- Provide the right physical interfaces to be connected to the camera for remote control
- Integrate the 5G S-NPN modem.

Although the specifications of this component have been defined and prototyped, an organizational issue has prevented us from fully implementing this part. We have however successfully performed tests of similar functions using off the shelf solutions, and software developed in the project.

Media Orchestration and Control Gateway (MOCG)

Successfully incorporating a wireless camera into live media production means:

- Knowing that the camera is available (device on-boarding) to connect to the production, is authorised to connect, and its location on the network.
- Knowing how the camera is configured and if necessary, change that configuration as required by the production and the technical setup.
- Being able to connect & start and disconnect & stop the camera into the production and have any stream format conversion carried out automatically.
- Connecting other signals needed for operational or technical reasons. These might include real-time camera control (see below), timing reference, viewfinder return video, teleprompter feeds, camera tally, production intercom, follow focus, tracking for VR or AR applications, and lighting control.

Device on-boarding relates (in the simplest case) to the provisioning of the Network Access Credentials on the device (e.g. SIM card) and in the S-NPN network. In addition, some basic connectivity parameters, including DNS server address, need to be provisioned.

We decided to build on the interoperability approach developed for the AMWA Networked Media Open Specifications (NMOS) '(1)', in particularly the IS-04 and IS-05 specifications for discovery and connection of networked media devices.

Cameras typically do not support NMOS directly yet, but often provide control interfaces, so we have developed a Media Orchestration and Control Gateway (MOCG), and a MOCG client that forms part of the Camera Interface Unit, to interface cameras into an NMOS environment. We have investigated the use of the lightweight MQTT (originally 'MQ Telemetry Transport' in reference to the IBM MQ product line) protocol 'ISO (5)', which provides a fast publish-subscribe messaging interface well suited to low-power applications such as mobile wireless cameras.

An important requirement is to allow the control of remote devices from different locations (e.g., from a main studio, or a home working studio). Remote camera control environments that control signals coming in and out of a camera are quite complex, and each camera vendor has its own proprietary control protocol and implementation. As our aim was to be as device-agnostic as possible, we investigated a core set of camera controls commonly used in live production environments and have successfully tested the following novel solution.

Control messages are carried using AMWA IS-07, a NMOS specification to convey time-related data over a media network. IS-07 supports MQTT transport, allowing a consistent approach with the project's use of MQTT for camera discovery and connection. The CIU translates this to the proprietary protocols used by the camera. Where appropriate, the project has used a commercial product to help with this.

The MOCG demonstrates how control plane interoperability between different media networks – which has often been overlooked in the broadcast world – can be taken further with its use of NMOS and was therefore included in the European Commission's Innovation Radar programme 'EC (3)'.

Media Gateway (MG)

The use of both wired and wireless cameras in a production introduces some further challenges:

- There is limited radio spectrum available within wireless networks, and un-compressed video is not practical. This means that compression is required, which can lead to increased latency, lower visual quality, or a combination of the two.
- Wired network sources are often genlocked, which may not be possible on a wireless network.
- Wired media networks often use multicast communications, which may also not be possible on a wireless network which are more likely to support unicast solutions.

Currently, HEVC compression 'ISO (6)' with a low latency profile is used for video, while Opus or PCM (Pulse-Code Modulation) are used for audio. A Media Gateway (MG) component was developed to integrate the 5G network with the media production network.

The MG performs stream, address and multicast-unicast conversion under the control of the MOC Gateway. When multicast is not supported on the 5G network, the MG can create multiple unicast replicas of the same multicast stream.

The major responsibility of the MG is to adapt the streams between across different formats. For example, the MG receives HEVC over RTP and converts it to uncompressed video over ST 2110. Conversely, the MG receives the return video from the production studio and converts it to HEVC/RTP to deliver it to the venue.

Additionally, the MG can receive or send RIST (Reliable Internet Stream Transport) or SRT (Secure Reliable Transport), which can be used, not only as the transport from the cameras to the studio and back, but also to forward the streams to a virtual production studio on a Cloud. RIST and SRT offer functionality for sending data over a non-QoS provisioned wide area network.

For testing purposes, the MG was deployed as an appliance, but it will be possible to deploy it in a fully virtualised environment, as long as the infrastructure provides the required GPU (Graphical Processing Unit) and network acceleration hardware.

5G S-NPN Network Configuration

The 5G system is configured so that radio-related packet losses are handled by the 3GPP radio layer, and congestion-related packet losses – which may occur because of other devices, or other streams to or from the same device – are managed by a QoS configuration. This avoids the need for RTP retransmission and reduces the buffering needs.

5G provides a number of low-level robustness features, including adjusting the Modulation and Coding Scheme (MCS) to the radio conditions, and error correction. If these robustness features are insufficient (e.g., in a noisy radio environment), some signals can be prioritised over others. Signals that programme video and audio for instance, as well as timing signals, have priority over tally information or lighting control. 5G includes the concepts of ‘QoS Flows’ and ‘Network Slicing’ to enable such prioritisation, and implementations are starting to provide API (Application Programming Interface) access for these.

Time Synchronisation

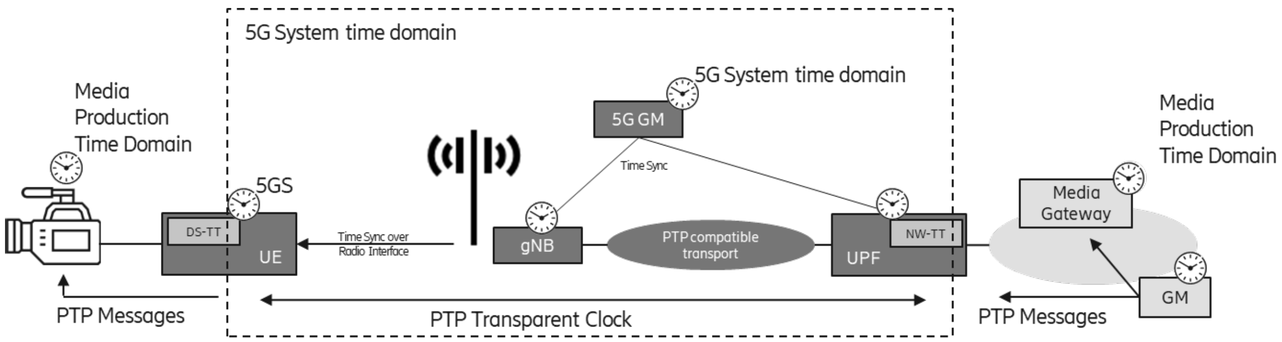

Figure 3 - PTP-enabled synchronisation

To differentiate from the fully asynchronous multi-camera setups with downstream synchronisation currently available on the market, 5G-RECORDS has considered a genlock-type approach, i.e., to capture the frames at the exact same time. The idea was to investigate the use of the IEEE 1588 Precision Time Protocol (PTP) ‘IEEE (4)’ over 5G to derive both the genlock signal and timestamp frames. Providing precise time information can however be challenging in 5G environments due to varying latencies of radio transmission.

As illustrated in Figure 3 (where GM stands for Grandmaster), the 5G network acts as a PTP Transparent Clock, based on how time synchronisation is supported in 3GPP. This was tested in an Ultra-Reliable Low-Latency Communication (URLLC) testbed network developed by Ericsson. This evaluation showed that a synchronisation accuracy of less than 4 µs can be achieved (potentially even improving over time). This is a promising result for genlock and for timestamping of the RTP media packets, although further tests are needed. The detailed description of the testbed and results is available in ‘Kostiukevych (7)’.

BENEFITS FOR BROADCASTERS

Our architecture has demonstrated the feasibility of using a 5G S-NPN network for live media production with multiple wireless cameras. With the correct architectures, these networks can support enhanced uplink, improved quality of service and multi-function bi-directional links. This means that we can use a single radio link to provide different services tailored to the needs of individual productions.

In the correct circumstances, when networks are located on their own dedicated spectrum, changes to basic network configurations may be possible. By reassigning TDD (Time Division Duplex) allocations, we can achieve uplink throughput of up to 300 Mb/s in a 100 MHz channel using mid-band spectrum. However, changing the TDD patterns is typically not possible in a conventional network as it would interfere with other services and adjacent networks.

The gateway devices developed by this project enable us to manage wireless devices in the same way that we manage wired devices within the studio. Previously it has only been possible to integrate as far as the receive unit, but with IP networks it is possible to integrate from the camera head and therefore incorporate essential functions such as timing, configuration, and control.

S-NPNs also offer enhanced security over other types of radio networks, as only devices known and registered to the network operator are allowed to connect. This helps with the heavy contention seen on public networks at busy events.

FUTURE OPPORTUNITIES FOR IP-BASED PRODUCTION

Because of all these new opportunities, 5G S-NPNs can be seen as an enabler to the move to IP production, which in turn unlocks several well documented benefits.

The opportunity to work in an IP environment means that one can more easily integrate with new ways of working such as cloud-based and remote production. By deploying a small-scale S-NPN at a facility, it would be possible to not only move video to a production centre but also have control over fixed-rig devices. This could be applied in a number of production scenarios including:

- Lower-tier sports production
- Conference coverage
- Political debates
- Festivals and cultural events extra coverage
- Production for web and mobile content

We expect new models of connected production to be able to provide increased coverage of events at a lower cost, thus enabling more services to be available to our audiences.

We are starting to see commercial opportunities for both media technology providers and the telecoms industries. There will need to be skills and knowledge transfer between the two. There are some challenges such as the agility required for media production which does not always fit in with MNOs (Mobile Network Operators) long term planning and deployments. New business models could also emerge to support specialist services to support the media production industry especially in network and spectrum management.

CONCLUSION

In 5G-RECORDS we have started investigating the viability of 5G S-NPN for multi-camera media production and identified how to improve interoperability with existing media production networks. Some new components – which do not currently exist in the market – have been designed and implemented (partially or fully), namely a Camera Interface Unit, a Media Orchestration and Control Gateway, and a Media Gateway.

At the time of writing, tests on end-to-end latency, jitter, throughput, packet loss, and PTP performance are in progress and will be documented in 5G-RECORDS public deliverables and other papers.

5G-RECORDS has identified opportunities to provide better control-plane interoperability between 5G networks and wired broadcast facilities and is discussing with AMWA how NMOS might be extended. Project partners have also provided inputs to the 3GPP study item on Media Production over 5G NPNs ‘(11)’.

There are still several areas requiring further work. The current commercially available 5G components (Release 15) ‘(10)’ do not fully support some features such as PTP timing, and we also need to work to better support these services in the user equipment used in production.

Although this paper has focused on the use of S-NPN for media production, some of the concepts explored here could also be realised using Public Network Integrated Non-Public Networks (PNI-NPN), which can secure access to a part of the network for dedicated use of a specified user.

We expect both 5G networks and media production networks to evolve over time to support increased bandwidth and higher quality connectivity. Future releases by 3GPP will have features that support media industry requirements (e.g. improved PTP, enhanced uplink and lower latency).

ACKNOWLEDGMENTS

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